Shallow Scattering Layer (SSL): Emergence Behaviors of Coastal Macrofauna

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LONG-TERM GOALS

Our long-term goals are to understand — to an extent that allows quantitative prediction — important interactions among acoustic propagation, marine organisms, particles (including sediments), solutes and moving fluids. The reason for these goals is to allow us to solve interesting forward and inverse problems in the marine environment.

OBJECTIVES

The objectives of this work are to develop a predictive understanding of emergence by coastal macrofauna in one region. By emergence we mean leaving the seabed to become part of the plankton or nekton, which typically occurs at night. In high-frequency acoustic records, this emergence appears as a "shallow scattering layer" that typically leaves the seabed after dusk and returns before dawn. Emergence and re-entry in shallow water appear to represent an evolutionary solution that avoids visual predation analogously with oceanic "deep scattering layers." In the coastal zone, the water is simply too shallow to provide a holoplanktonic solution.

The region selected for this work is midcoast Maine in the vicinity of the Darling Marine Center, which is located, mid-estuary on the lower Damariscotta River. The region was chosen for its diversity of estuarine and coastal environments, including a range of optical properties in river and coastal waters. We caution that it may be more representative of coastal waters than of an estuary because of the small freshwater input.

APPROACH

The approach has three phases that correspond to three field years, and we are completing the final field year. The first was a survey of the Damariscotta, Sheepscot and Kennebec estuaries for the presence and identity of emergent macrofauna. The second phase entailed collection of acoustic data to afford temporal and spatial resolution of the phenomenon in a region of strong emergence behavior, the mid-estuary Damariscotta. Trapping results led us to believe that the emergence would be strongly modulated by the tides as well as by irradiance. The last phase entails identifying environmental cues that allow prediction of the occurrence and character of emergence events by combination of acoustics to locate interesting, repeatable, events in space and time, and other sampling and environmental measurements to tests hypotheses concerning relevant environmental cues.

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WORK COMPLETED

In the first year we completed an initial regional survey, based on over 90 emergence-trap samples. Trap and net samples have been distributed over the next two years to provide physical samples for developing acoustic inversion models and assuring the biological identities of the scatterers. They comprise several traps each week. On the basis of number and diversity of emergent fauna and for logistics we selected the mid-estuary Damariscotta as the preferred site for the second phase. We have continued to collect quadruplicate emergence-trap samples several times per week to maintain a record of sizes and identities of emergers, in part for acoustic inversion. More importantly, we have now collected TAPS-6 (Tracor Acoustic Profiling System with 6 frequencies from 265 kHz to 3 MHz; manufactured by BAE SYSTEMS, Inc.) data from mid June through November 2001, largely accompanied by ADCP profiles. The data are "gappy" because of punctuated problems with corrosion and electrical components, but we have many series long enough for powerful time-series analysis. The series stopped in late November because of instrument problems that were not resolved until June 2002, despite our best efforts and those of the BAE SYSTEMS team (primarily Charles Greenlaw and D. Van Holliday). All 2002 data are vertical, up-looking profiles.

The 2002 work was to be carried out with two TAPS-6 instruments. We have succeeded only in September 2002 in such parallel collection and now have two time series underway, although we are still experiencing difficulties with one of the two instruments. Part of the delay was a deliberate decision to keep one TAPS-6 instrument at Friday Harbor, San Juan Island, WA, to run a time series in support of interpretations of other acoustic data (from the PAL instrument, see below). Trap samples in the 2000 and 2001 field seasons established that the primary macroscopic migrators (larger than copepods) were the mysid species *Neomysis americana* and a larger decapod shrimp (*Crangon septemspinosa*). Acoustic records showed complex emergence patterns, with emergence events shortly after dark but late in the summer also at various other times. An obvious hypothesis for nocturnal emergence is the avoidance of light levels adequate for target discrimination by visual predators, and one graduate student (Heather Uhden) has been testing this idea through various optical models and measurements that involve time variations in both irradiance and turbidity. A less obvious and not necessarily mutually exclusive hypothesis is that benthic diatoms produce oxygen at the seabed under daylight but help to drive anoxia in the seabed at night. Dave Thistle and his postdoc, Kay Vopel, came to our laboratory in July 2001 to test this hypothesis with microelectrode measurements and examine the meiofaunal components of the emergence events. A second student (Leslie Taylor) has been exploring the relation of emergence events to tidal phases and velocities.

RESULTS

Benthic diatom production was insufficient to drive a diurnal cycle in oxygen concentration at the seabed, allowing us to discount nocturnal anoxia as a local driver of emergence. Major emergence events occurred at low light levels. Rather than one dominant emergence peak or mode per night, as seen in Puget Sound (Kringel *et al.,* in review), we often found many, but two usually dominated (Fig. 1). The first occurred shortly after dusk. A second event occurred near the first peak in tidal velocity after dusk (Fig. 2), irrespective of flow direction (incoming or outgoing tides). Depending on the phasing of the tides with the diurnal cycle, the two may coincide. When they are not coincident, the tidal emergence peak is generally the larger of the two. Much to our surprise, both events are dominated by the same mysid species, *N. americana.*

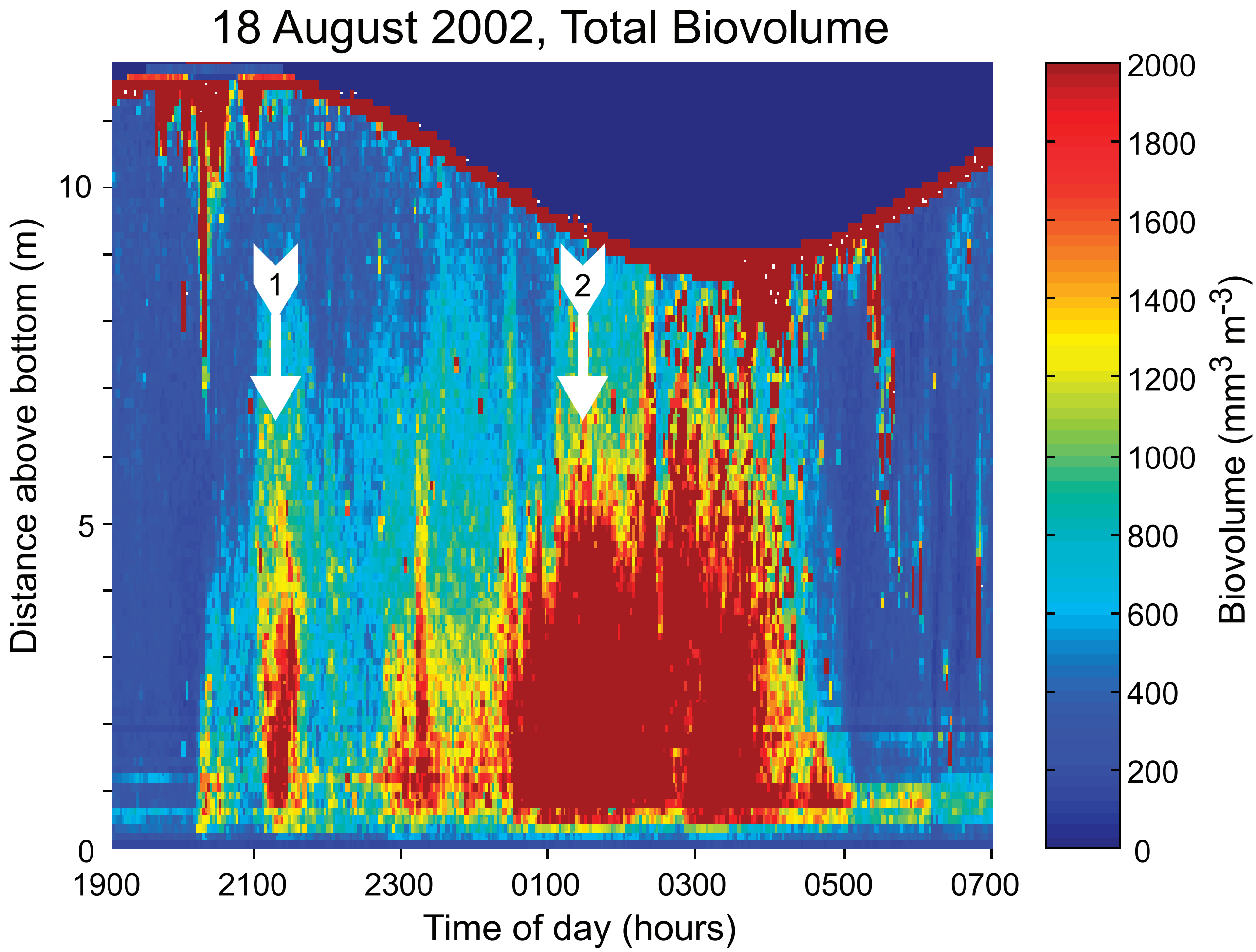

Figure 1. An example of multiple peaks in emergence. The .rst peak (1) occurs shortly after dusk. The second peak (2) occurs shortly after the highest tidal velocity that occurs after dusk. The eye detects a small event prior to 2100 hours and another near 2300 hours, but we use an algorithm that in general succeeds in identifying the two largest abundance increases.

Tidal modulation of mysid migrations, to our knowledge has been reported only for intertidal species that maintain position relative to the water line on wave-exposed beaches (Takahashi and Kawaguchi 1997). N. americana does not occur intertidally. We hypothesize that mysids may gain camouflage from tactile predation by coincidence of emergence with peak velocities and turbulence intensities.

IMPACT/APPLICATIONS

Our goal was to gain predictive capability of emergence timing and intensity. We have now achieved a predictive capability with respect to timing and are working toward quantitative prediction of near-seabed backscatter intensity and column scattering strength as a function of time.

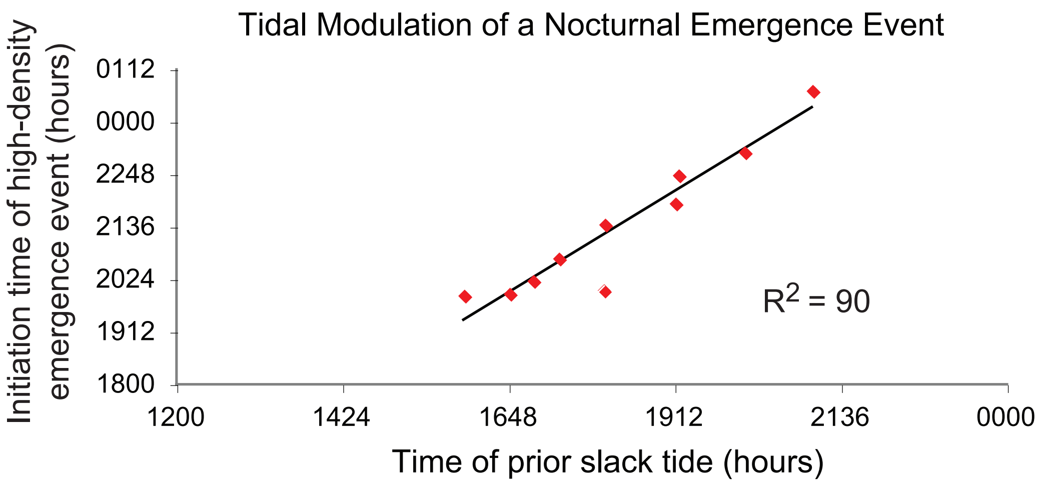

Figure 2. Regression of the time of the beginning of the high-density emergence event (indicated by the numeral 2 in Fig. 1) versus time of the prior slack tide for data from 2001. Note the good, linear .t, indicating strong tidal modulation of this timing.

RELATED PROJECTS

This project is related to some components of the ONR DRI on High-Frequency Sound Interaction in Ocean Sediments (coordinated by Eric Thorsos of the Applied Physics Laboratory of the University of Washington). Evolving details can be found at http://www.apl.washington.edu/hfsa-dri/Program/prog.html. As part of that effort, Sara Lindsay and I are modeling the microtopographic impacts of fish feeding (N00014-02-1-0091).

Chris Jones of APL (N00014-00-1-0034) and Pete Jumars of the University of Maine (N00014-00-1-0035) are developing a cluster of instruments that allow experimental testing in convenient field sites of the putative effects of organisms whose field abundances can be manipulated. The concept is of a Portable Acoustic Laboratory (PAL) that can be deployed wherever there is a source of power and a data cable for download. In this way mechanisms can be investigated without waiting for an expensive field experiment to be fielded. The system currently has 300- and 120-kHz transducers to ensonify the sediments. One future target of this system may be the effects of emergent animals.

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Takahashi, K. and Kawaguchi, K. 1997. Diel and tidal migrations of the sand-burrowing mysids, *Archaeomysis kokuboi*, *A. japonica* and *Iiella ohshimai*, in Otsuchi Bay, northeastern Japan. *Marine Ecology Progress Series* 148: 95-107.

PUBLICATIONS

Kringel, K., P.A. Jumars and D.V. Holliday. A shallow scattering layer: High-resolution acoustic analysis of nocturnal vertical migration from the seabed. This manuscript has been revised and resubmitted to *Limnology and Oceanography* and is posted at the url noted on the front page of this document.